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## PROCESS FOR MAKING FUSED JUNCTION SEMI- CONDUCTOR DEVICES WITH ALKALI METAL- GALLIUM ALLOY

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This invention relates to fused junction semiconductor devices and more particularly to an improved method of producing a fused junction in an active impurity-doped semiconductor starting crystal and to such improved devices.

In the semiconductor art a region of monatomic semiconductor material containing an excess of donor impurities and yielding an excess of free electrons is considered to be an N-type region, while a P-type region is one containing an excess of acceptor impurities resulting in a deficit of electrons, or stated differently, an excess of holes. When a continuous solid crystal of semiconductor material has one N-type region and one P-type region, it is termed a P-N junction semiconductor device, while a specimen having two N-type regions separated by a P-type region is termed an N-P-N junction semiconductor device.

On the other hand, it is sometimes desired to produce in a continuous solid crystal of N-type semiconductor material, an N-type region fused thereto to form therewith an ohmic contact to an external circuit. The term junction device, as herein utilized, is intended to include all of the aforementioned type semiconductor devices.

The term "semiconductor material," as utilized herein, is to be construed as including either germanium, silicon, germanium-silicon alloy, indium-antimonide, aluminum-antimonide, gallium-antimonide, indium arsenide, aluminum-arsenide, gallium-arsenide, lead sulfide, lead-telluride, lead-selenide, cadmium-sulfide, cadmium-telluride, and cadmium selenide. Although for the purpose of clarity the present invention will be disclosed with particular reference to germanium, it is to be understood that silicon or any of the other hereinabove mentioned semiconductor materials may be equally well utilized according to the method of the present invention.

The term "active impurities" is used to denote those impurities which affect the electrical characteristics of semiconductor material, as distinguished from other impurities which have no appreciable effect upon their characteristics. Generally, active impurities are added intentionally to the starting semiconductor material, although in many instances, certain of these impurities may be found in the original material. Active impurities are classified as either donors, such as antimony, arsenic, bismuth, and phosphorus, or acceptors such as indium, gallium, thallium, boron, and aluminum.

In the prior art, junctions have been produced in semiconductor materials by either of two well known processes, namely, the crystal-pulling technique, wherein the junction is grown by withdrawing a seed crystal from a doped melt of semiconductor material, and the fusion methods wherein a region on a semiconductor specimen or crystal of one conductivity type is converted to the opposite conductivity type. This invention deals exclusively with the latter class of devices.

According to a prior art fusion process for producing a fused-junction semiconductor device, a region of a semiconductor specimen of one conductivity type is con-

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verted to the opposite conductivity type by fusing thereto an active impurity, either alone or in alloy form. There will thus be produced a P-N junction as the starting semiconductor material retains the conductivity type as it originally existed, while a region of the opposite conductivity type is produced by the active impurity-doped alloy being fused thereto.

According to one method for producing a germanium N-P-N junction transistor, for example, two pellets of lead arsenic alloy are first prefused to opposite surface of a P-type germanium starting specimen. Thereafter, the combination is heated to a predetermined temperature above the melting point of the alloy, but below the melting point of the germanium, to melt the alloy pellets and to dissolve therein a predetermined amount of the adjacent germanium crystal, thereby creating two molten alloy regions of lead, arsenic, and germanium on the opposite surfaces of the crystal. The combination is then cooled at a predetermined rate to precipitate or redeposit onto the adjacent crystal a portion of the germanium, together with substituted atoms of arsenic, thereby producing two regrown regions of N-type germanium which may constitute the emitter and collector regions, respectively, of a transistor.

Another method for producing a fused-junction transistor is disclosed in copending U. S. patent application Serial No. 417,081 for "Fused Junction Transistors with Regrown Base Regions," by Justice N. Carman, Jr., filed March 18, 1954. In the copending application there is described an alternate technique for producing a fused-junction, high-frequency transistor. According to the basic concept therein disclosed, a fused-junction transistor includes a base region created by converting a portion of a semiconductor starting crystal of one conductivity type to the opposite conductivity type, the unchanged portion of the starting crystal constituting the collector region. The emitter region and its associated junction are then formed on the opposite or exposed surface of the base region by a second fusion operation, or by electro-forming therewith a properly doped conventional wire whisker.

According to these methods the alloy button upon cooling freezes out atop the regrown region at the end of the fusion operation and it is later either dissolved by a suitable solvent, after which another P-N junction may be formed with the regrown region, or alternatively it is not removed, but is instead used as an ohmic contact to the underlying regrown region. Such button can only be used as an ohmic contact when it is of the same conductivity type, i. e., when the active impurities in the alloy pellet are of the same type as those of the semiconductor starting crystal to which it is fused. In all of these methods wherein an alloy button containing the active impurity is used to form a junction it is necessary, if the junction is to be formed at moderate temperatures, to remove all oxides which may have formed along the fusion interface and to improve the wetting of the metal to the semiconductor starting crystal. Previously, success could only be achieved by the use of chemical fluxes placed on the wafer along with the alloy at the time of fusion.

The present invention obviates the requirement for the addition of chemical fluxes to allow for wetting and for removing of the oxide coatings at the fusion interface. Various alkali alloy fluxes have been used to perform this goal; however, they all require very high temperatures, e. g., of the order of magnitude of 800 degrees centigrade to melt the flux and perform the fusion. Further, the action of many of these fluxes on the surface of the wafer results in extensive damage to effective lifetime of charge carriers of the crystal because of the increased surface velocity induced by the damaged surface